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Transit Vehicles Intelligent Scheduling Optimization Based on the Division of Characteristic Periods

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Abstract

Vehicle scheduling problem (VSP) is a vital part of the bus scheduling scheme based on the bus timetables. In this paper, the various basic problems that influence the vehicle scheduling scheme are analyzed. Then, the characteristic periods are divided by using the ordered samples clustering of travel time based on vehicle real-time GPS data. According to the parameters such as the vehicle headways, vehicle turnaround time, the first and last stations' layover time in different characteristic periods, the vehicles scheduling optimization model is established with the object of the minimum vehicles quantity and the minimum total operating costs. The single depot vehicle scheduling problem is converted to the general fixed job scheduling matters; the practical method of vehicle dispatch and vehicle operational method are given. Finally, the model is applied with the actual running data of an example bus line and the corresponding vehicle turnover program is given.

keywords: bus dispatching；vehicle scheduling problem；fixed job scheduling；cluster analysis on travel time；characteristic periods division

1 Introduction

Vehicle scheduling problem plays an important role in the bus scheduling management plans, the scientific vehicle scheduling needs to satisfy the requirements of the information, intelligence; to ensure the passenger transport work completed effectively. After the bus schedule is determined, the next step is to arrange the vehicles to complete each trips task in bus schedule. The vehicle scheduling needs to make full use of the vehicle, to satisfy the given schedule trips demand, to make the vehicle's total quantity minimum which is also to satisfy passenger demand, to maximize the benefits of the bus operating company at the same time.

Some scholars have conducted research for the public transport vehicle scheduling problem. Gavish and Shifler (1978) convert the vehicle scheduling problem to a mathematical model which satisfies the goal of the minimal number of vehicles and the minimal vehicle space-time in the running process under the trips completed constraints, and then gives the solution of the model algorithm. Bodin and Golden (1981) adopt a two-stage

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method for solving the single depot vehicle scheduling problem (Single Depot Vehicle scheduling, SDVS). Brazil's three scholars Maikol M. Rodriguesa, Cid C.Sottzab, and Arnaldo V.Moura (2006), give the optimized vehicle plan to reduce operating costs under the passenger demand and constraints of technology conditions.

It's worth noting that, previous vehicle scheduling plan lacks information acquisition data support, it cannot be timely adjusted and updated, resulting in the bus cannot satisfy the changing demand for passenger transport; On the other hand, due to the lack of method for vehicle travel time records, the using of the vehicle lacks considering of the real-time road driving conditions, the scheduling table cannot be executed perfectly. Today, the vehicle scheduling problem should pay attention to the acquisition of the information data, and consider the different characteristic period, because the turnaround time of the vehicle and the vehicles demand quantity are not immutable in different Characteristic periods due to congestion status. So, in this paper, the characteristic periods are divided by using the ordered samples clustering of travel time based on vehicle real-time GPS data. Then, according to the parameters such as the traffic space, vehicle turnaround time, the first and last stations' layover time in different characteristic periods, the vehicles intelligent scheduling optimization model is established with the object of the usage of the minimum quantity vehicles and the minimum total operating cost. And the vehicle scheduling problem is converted to the general fixed job scheduling matters, the practical method of vehicle dispatch and vehicle turnaround program are given.

2 Bus Vehicle Scheduling Optimization Model

2.1. Description of the problem

Vehicle scheduling is based on a bus timetables, it shows the number of vehicles required and the operation situation of each vehicle: the time to departure, which trips to carry, the time back to the depot and so on. In the preparation of the vehicle scheduling plan, various factors need to be considered. You need to take full account of the services, scheduling and running time in bus timetables; the vehicle's stay and overhaul time; restrictions and regulations, cost factors. Then, determine the range of fleet size; reduce the number of vehicles by scheduling and adjusting departure time. After the feedback and analysis, the preparation of the optimal vehicle scheduling table is compiled finally, as shown in Fig.1.

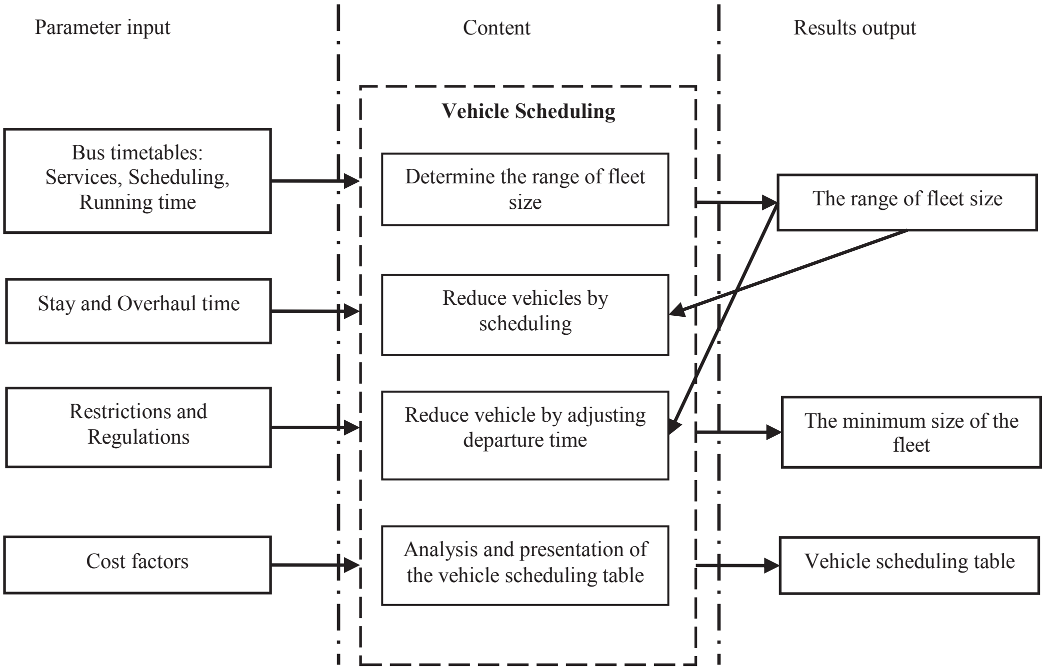

Figure 1. Preparation vehicle scheduling Table

Therefore, vehicle scheduling problem can be described as follows: in a characteristic period, vehicle scheduling problem is a vehicle assignment problem under timing constraints with the objective of minimizing the bus company operating costs. The practical problems to be addressed in this model is making the each trips in schedule should be executed, simultaneously, the number of vehicles used and the total operating costs should be minimized.

2.2. Assumption

(1) The smallest unit of time is 1 minutes;
(2) The vehicle's passenger capacity is sufficient to satisfy passenger demand;
(3) Bus schedule is known;
(4) In the same Characteristic periods, the vehicle departure interval, travel time, stop time are invariant;
(5) The vehicle stop costs (time costs), space time costs (vehicle·km) are constant.

2.3. Basic vehicle number calculations

The number of vehicles to be equipped in each bus line will be different in different characteristic periods due to traffic conditions. Peak passenger flow period requires more vehicles comparing to passenger flat peak. Therefore it needs to calculate the basic number of vehicles to provide the reference value in model.

(1) Vehicle headways

Vehicle headways are given by the bus timetables.

(2) Number of vehicles equipped

In the preparation of the bus operation plan, number of vehicles equipped refers to the number of vehicles traveling in the turnaround time of a round trip, also known as the turnover constants G_T.

$$G_T = \frac{T_T}{t_h}(veh) \qquad (2\text{-}1)$$

Where T_T represents turnaround time (min)； $\bar{t}_h$ represents average vehicle headways.

(3) Basic number of vehicles

Basic number of vehicles refers to the number of maxima in each characteristic period.

$$m = \max\{m_1,\ m_2,...,m_K\} = \max\{\sum_{i=1}^{I} G_{Tik}\} \quad (2\text{-}2)$$

Where m represents basic number of vehicles； m_k represents number of vehicles in k charecteristic period； k represents the k charecteristic period； i represents the i trips in the k charecteristic period.

2.4 .Vehicles - Trips matching

After the reference value - basic number of vehicles is determined; the next step is the vehicle - trips matching. It will use the current vehicles to complete the trips task reasonably. In this paper, the fixed job scheduling problem in the theory of portfolio optimization is applied to establish a transit vehicle scheduling model.

Fixed job scheduling problem can be described as follows: consider a set of n jobs $J = \{J_j \mid j = 1, 2, \ldots, n\}$, a set of m processors $P = \{P_k \mid k = 1, 2, \ldots, m\}$,Each job can only be processed by one processor at the same time , once began cannot be interrupted until the processing is completed. Each job has a fixed start processing time t_{rj} and an end processing time t_{dj} .A mapping function exists between the processors and jobs $P \to J$. That is, for $\forall P_k \in P$, there exists a subset of jobs $S_k \in J$, the processors P_k in can process any job of set S_k . The question is whether to seek a processor arrange program that all the jobs can be processed according to the mapping relationship, and making the total processing costs lowest. Based on the sort labeling method, the problem is referred to as:

$$P_m \left| Fixed\ Job, P \to J \quad Mapping \right| \min z = \sum_i \sum_j C_{ij} X_{ij} \quad (2\text{-}3)$$

Where P_m represents parallel processors; $\min z = \sum_i \sum_j C_{ij} X_{ij}$ represents the number of missed tasks.

1) Optimization goals

The optimization goal in bus vehicle scheduling model is to minimize the total operating costs under the premise of completing all the trips tasks.

The vehicles to be deployed corresponding to processors are referred to $P = \{P_i \mid i = 1, 2, \ldots, m\}$; the bus trips corresponding to the jobs are referred to $J = \{J_j \mid j = 1, 2, \ldots, n\}$; each trips has its own departure and arrival time referred to $J_j = \left[t_{oj}, t_{dj}\right]$.

So, the single line bus vehicles scheduling problem can be represented as

$$V_m \left| Fixed\ Job, V \to T \quad Mapping \right| \min z = \sum_i \sum_j C_{ij} X_{ij} \quad (2\text{-}4)$$

Where V_m represents m vehicles;

$V \to T$ represents vehicle-trips matching relations

C_{ij} represents the operating costs of vehicle i completing trips j

The objective function is:

$$\min z = \sum_i \sum_j C_{ij} X_{ij} \quad (2\text{-}5)$$

Where $X_{ij} = \begin{cases} 1 & \text{The bus trips is assigned to the vehicle} \\ 0 & \text{Trips is not assigned to the vehicle} \end{cases}$

2) Constraints

① At the same time each vehicle runs one trips;

$$\sum_{T=\langle\alpha\rangle}^{\langle\alpha+t_{running}+t_{stay}\rangle} x_{ij} \le 1, T = 1,2,...,n$$

Where $\langle\alpha\rangle$ represents Trips executed by vehicle at the moment α ; $\langle\alpha+t_{running}+t_{stay}\rangle$ represents the last trips before the moment $\alpha + t_{running} + t_{stay}$; $t_{running}$ represents the running time of the given trips; t_{stay} represents the stay time at stops of the given trips.

② Each trips can be executed by only one vehicle and once began cannot be interrupted until the trips is completed;

$$\sum_{i=1}^{n} x_{ij} = 1, T = 1,2,...,n$$

③ Vehicles and trips should match;

$$\beta_{ij} = \begin{cases} 0 & \text{Vehicle } \mathrm{V}_i \text{ and trips } \mathrm{T}_j \text{ is matched} \\ 1 & \text{Vehicle } \mathrm{V}_i \text{ and trips } \mathrm{T}_j \text{ is not matched} \end{cases}$$

Thus, the entire transit vehicle scheduling model can be represented as:

$$\begin{cases} \min z = \sum_i \sum_j c_{ij} x_{ij} \\ s.t. \\ x_{ij} = 0,1 \quad \beta_{ij} = 0,1 \\ \sum_{i=1}^{n} x_{ij} = 1, T = 1,2,...,n \\ \sum_{T=\langle\alpha\rangle}^{\langle\alpha+t_{running}+t_{stay}\rangle} x_{ij} \le 1, i = 1,2,...n \end{cases} \qquad (2\text{-}6)$$

2.5. Algorithm design

First, define the variable label in algorithm: for each vehicle, the fixed label number $V(i) = 1,2,\ldots,m$ is determined, the set of vehicles $V = \{V_i \mid i = 1,2,\ldots,m\}$ is determined too. The order of the vehicle to execute the scheduling bus trips is determined based on the value V_i :

$$T(j) = \begin{cases} i & \text{The bus trips is assigned to the vehicle } \mathrm{V}_i (i = 1,2,\ldots,m) \\ 0 & \text{Trips is not assigned to the vehicle} \end{cases}$$

$$\beta_{ij} = \begin{cases} 0 & \text{Vehicle } \mathrm{V}_i \text{ and trips } \mathrm{T}_j \text{ is matching} \\ 1 & \text{Vehicle } \mathrm{V}_i \text{ and trips } \mathrm{T}_j \text{ is not matching} \end{cases}$$

The calculation procedure is as follows:

Step1. Each vehicle's departure time is represented as a departure event; all the departure events are sorted by the time order from small to large: $z_1 \le z_2 \le \ldots \le z_n$. Initialize, P and $P(i)$, Counter=0.

Step2. Assume z_k is a downlink departure event (when z_k is an uplink departure event, the algorithm is similar), corresponding trips is marked as T_k , find the $V_k \in V$ to satisfy

$$\begin{cases} \beta_{kj} = 0 \\ V(k) = \min\{V(i) | i \in V\} \end{cases}$$

Where $V(k) = \min\{V(i)|i \in V\}$ represents select the optimal vehicle with smallest label numeral, it will take a comprehensive consideration of space-time costs and stay at stops costs.

As for β_{kj} :

① Assume z_{k-1} is an uplink departure event, the corresponding trips is T_{k-1} ,

$$\begin{cases} when z_k \geq z_{k-1} + t_{u-running} + t_{u-stay} & then, \beta_{kj} = 0 \\ when z_k < z_{k-1} + t_{u-running} + t_{u-stay} & then, \beta_{kj} = 1 \end{cases}$$

Where $t_{u-running}$ represents the running time of the uplink trips; t_{u-stay} represents the stay time at stops of the uplink trips.

② Assume z_{k-1} is an uplink departure event, the corresponding trips is T_{k-1} ,

$$\begin{cases} when z_k \geq z_{k-1} + t_{u-running} + t_{u-stay} + t_{d-running} + t_{d-stay} & then, \beta_{kj} = 0 \\ when z_k < z_{k-1} + t_{u-running} + t_{u-stay} + t_{d-running} + t_{d-stay} & then, \beta_{kj} = 1 \end{cases}$$

Where $t_{d-running}$ represents the running time of the downlink trips; t_{d-stay} represents the stay time at stops of the downlink trips.

If P_k exists，then assign values

$T(j) = k,$

$m = m - 1,$

$V = V - \{V_k\};$

Where, $V_i \in V$ and $V(i) > V(k)$;

Modify the vehicle label number and assign again: $V(i) = V(i) - 1$; or

$T(j) = 0 \quad Counter = Counter + 1$

Assume $z_k + t_r + t_s$ is the event of executing corresponding trips T_k, then

$m = m + 1$

$V = V + \{V_i | i = T(j)\}$

$V(T(j)) = m$

Step3. $k = k + 1$;

Step4. If $k \leq n$, skip to step 2;

Or stop calculation, output $T(j), j = 1, 2, \ldots, n, \quad Counter$.

3 Characteristic periods dividing and cost analysis

Travel time is not a fixed value due to traffic conditions and changes in passenger flow. The length of the travel time influences the value of the operating costs C_{ij} in different Characteristic period. Based on vehicle real-time GPS data using cluster analysis methods, Characteristic period is divided and the period operating costs is calibrated. The characteristic periods dividing is actually an ordered sample clustering problem.

3.1. Fisher algorithm of ordered clustering

Ordered samples are the samples arranged in sequence according to certain requirements, the classification can not break this order.Assume $x_1, x_2, ..., x_n$ is an ordered set of samples. Each class must be presented like the morphological $\{x_i, x_{i+1}, ..., x_j\}(i < j)$. C_{n-1}^{k-1} kinds of all possible method can divide samples into k classes. C_{n-1}^{k-1} is much smaller than C_n^k. Therefore, under some kind of loss of function, it is possible to find an optimum solution. Fisher invented an ordered sample clustering algorithm, it is guaranteed to find an optimum solution.

First, define $D(i, j)$ is the diameter of $\{i, i+1, ..., j\}$. The diameter of the class can be represented by a variety of methods. The commonly used method is the sum of squares of the value minus the mean：

$$D(i,j) = \sum_{t=i}^{j} (x_t - \overline{x_{ij}})^2 \qquad (3\text{-}1)$$

Define $b_{n,k}$ represents a method of dividing n samples into k classes.

$b_{n,k} : \{i_1 = 1, i_1 + 1, ..., i_2 - 1\}, \{i_2, i_2 + 1, ..., i_3 - 1\}, ..., \{i_k, i_{k+1}, ..., n\}$; $i_i = 1 < i_2 ... < i_k < n$

Define $L(b_{n,k}) = \sum_{j=1}^{k} D(i_j, i_{j+1} - 1)$ (3-2)

Where $i_{k+1} = n+1$ is the loss function of $b_{n,k}$ classification.

Because of the smaller of loss function value, the more reasonable classification. Let $b_{n,k}^*$ be the minimum solution of equation (3-2).

Fisher's calculation method is using the following two recursive formula:

$$L(b_{n,2}^*) = \min_{2 \le j \le n} \{D(1, j-1) + D(j,n)\} \qquad (3\text{-}3)$$

$$L(b_{n,k}^*) = \min_{k \le j \le n} \{L(b_{j-1}^*, k-1) + D(j,n)\} \qquad (3\text{-}4)$$

When $k = 2$, then $b_{n,2} : \{1, 2, ..., j-1\}, \{j, j+1, ..., n\}, 2 \le j \le n$

By the formula (3-2), we can get the formula:

$L(b_{n,2}) = D(1, j-1) + D(j,n)$

The optimal method is using the above equation to get the minimization value when $j(2 \le j \le n)$, we can get the formula (3-3).

We must notice that, divide *n* samples into *k* classes, it is equivalent to dividing n samples into two parts: $\{1, 2, ..., j-1\}$; $\{j, j+1, ..., n\}$

The $\{1, 2, ..., j-1\}$ will be divided into $k-1$ classes. For $\{j, j+1, ..., n\}$, it is one class. Obviously, $k \le j \le n$, so we can get the formula (3-4).

If $k(1 < k < n)$ is known, the method to find $b_{n,k}^*$ to make it the minimal loss function as following:

By the formula (3-4), if $k > 2$, find j_k to make

$L(b_{n,k}^*) = L(b_{j_k - 1, k-1}) + D(j_k, n)$

So, we can get the *k* class $P_k^* = \{j_k, j_k + 1, ..., n\}$, then find j_{k-1} to satisfy

$L(b_{n,k}^*) = L(b_{j_k - 1, k-1}^*) = \{L(b_{j_k - 1, k-2}) + D(j_{k-1}, j_k - 1)\}$

We can get the $k-1$ class: $P_{k-1}^* = \{j_{k-1}, j_{k-1} + 1, ..., j_k - 1\}$

Turn the cycle continues, we can get all the classes $(P_1^*, P_2^*, ..., P_K^*)$=$b_{n,k}^*$ .by the formula (4-3)(4-4), we will find the optimal solution $k_{n,k}^*$.

3.2. Characteristic periods dividing using ordered samples clustering

For a single line, average travel time can be statisticsed using the units time interval as a set of ordered samples. Based on the above Fisher algorithm the samples are clustered, the specific steps are as follows:
Step1. The average travel time by unit operating interval should be statisticsed (sample number is assumed to be *n*), composing of a set of chronologically ordered samples.
Step2. Calculate the diameter of all possible classes.

$$D(i,j)=\sum_{t=i}^{j}(x_t-\overline{x_{ij}})^2;$$

Where ($\overline{x_{ij}}=\frac{1}{j-i+1}\sum_{t=i}^{j}x_t$)

Step3. Calculate the minimal loss function table. Use $b^*_{i,j}$ represents the optimal solution for the first *i* samples into *k* classes. Its optimal loss function is $L(b^*_{i,j})$. When $j\le i\le n, 2\le j\le n$, the minimal loss of function table can be calculated by Fisher algorithm, as shown in Table 1.

Table 1. Minimal loss of function

	2	3	4	5	…	j
3	$L(b^*_{3,2})(k_{32})$	-	-	-	-	-
4	$L(b^*_{4,2})(k_{42})$	$L(b^*_{4,3})(k_{43})$	-	-	-	-
5	$L(b^*_{5,2})(k_{52})$	$L(b^*_{5,3})(k_{53})$	$L(b^*_{5,4})(k_{54})$	-	-	-
6	$L(b^*_{6,2})(k_{62})$	$L(b^*_{6,3})(k_{63})$	$L(b^*_{6,4})(k_{64})$	$L(b^*_{6,5})(k_{65})$	-	-
…	…	…	…	…	…	…
i	…	…	…	…	…	$L(b^*_{i,j})(k_{ij})$

k_{ij} indicates that are classified as one class. *i* is the *i* sample; *j* is the number of classification.

Step4. The number of classifications and optimal classification can be calculated by the ordinal clustering analysis.

3.3. Costs calibration of each characteristic periods

After the characteristic periods division determined, for the *k* characteristic period, the average travel time $\bar{t}_k$ can be calculate. Thus, the trips costs in *k* characteristic period is $c_k=\bar{t}_k\times c_0$; c_0 is the travel costs of a unit time (Unit: min).

Thus, the travel cost / time can be obtained, as shown in Table 2.

Table 2. Travel cost / time

Characteristic period	1	2	…	*k*	…	K
Travel costs	c_1	c_2	…	c_k	…	c_K

Wherein, the C_k corresponds to C_{ij} in vehicle scheduling model, thereby the optimal vehicle schedules can be obtained.

4 Case applied

One bus line in Shanghai is applied as an example using this model and algorithm. The working hours of this bus line is from 5:30am to10:30pm.

4.1. Characteristic periods dividing

Based on vehicle real-time GPS data analysis, the travel time/time diagram is obtained as Fig. 2 shows.

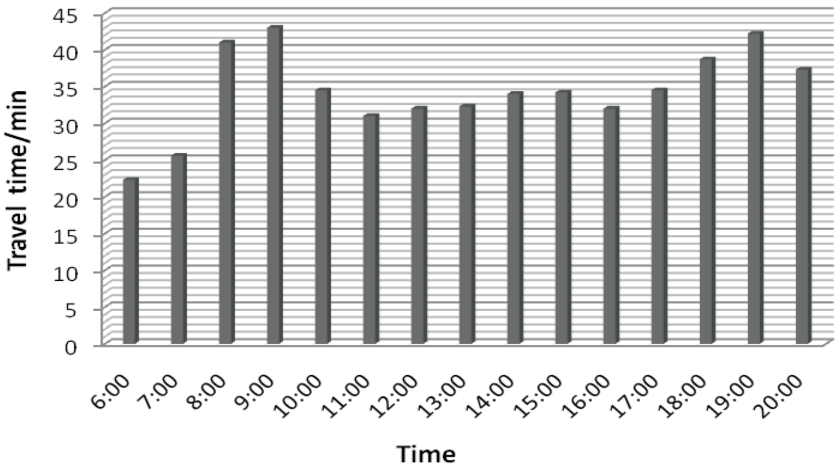

Figure 2. Travel time/time

The characteristic periods of trips travel time are divided using Fisher algorithm of ordered clustering described above. The specific steps are as follows:

Step1. The travel time of each period is converted to its proportion of the total travel time, as the Fig.2 shows, there are *15* periods, Ie $n = 15$ ordered samples.

Step2. Calculate the deameter of all possible classes.

$$D(i,j)=\sum_{t=i}^{j}(x_t-\overline{x_{ij}})^2;\ (\overline{x_{ij}}=\frac{1}{j-i+1}\sum_{t=i}^{j}x_t)$$

Step3. Calculate the minimal loss function table. Use $b_{i,j}^{*}$ represents the optimal solution for the first i samples into k classes. Its optimal loss function is $L(b_{i,j}^{*})$. When $j \le i \le 15$, $2 \le j \le 15$, the minimal loss of function table can be calculated by Fisher algorithm, as shown in Table 3.

Table 3. Minimal Loss of Function

i	j						
	2	3	4	5	6	7	8
3	0.0009(2)	-	-	-	-	-	-
4	0.0011(2)	0.0001(3)	-	-	-	-	-
5	0.0019(2)	0.0011(3)	0.0001(5)	-	-	-	-
6	0.0031(2)	0.0015(5)	0.0002(5)	0.0001(5)	-	-	-
7	0.0042(2)	0.0019(5)	0.0006(5)	0.0002(6)	0(6)	-	-
8	0.0055(2)	0.0021(5)	0.0008(5)	0.0002(6)	0.0001(6)	0(7)	-
9	0.0059(2)	0.0029(5)	0.0009(5)	0.0004(6)	0.0002(9)	0.0001(9)	0(9)
10	0.0062(2)	0.0031(5)	0.0013(5)	0.0005(9)	0.0003(9)	0.0001(9)	0(9)
11	0.0072(2)	0.0033(5)	0.0017(5)	0.0008(9)	0.0004(9)	0.0003(11)	0.0001(11)
12	0.0072(2)	0.0035(5)	0.0023(5)	0.0011(9)	0.0006(9)	0.0004(9)	0.0002(9)
13	0.0092(2)	0.0051(5)	0.0023(5)	0.0017(9)	0.0012(12)	0.0005(12)	0.0003(12)
14	0.0097(13)	0.0073(5)	0.0034(13)	0.0021(13)	0.0018(13)	0.0009(13)	0.0005(13)
15	0.0097(13)	0.0073(13)	0.0034(13)	0.0022(13)	0.0019(13)	0.0010(13)	0.0006(13)

Fig.3 describes the loss function curve, the value is the last line of Table 3. From the curve, when the classification number is *4*, the value of the loss function is *0.0034*. Loss function value has dropped small enough. In addition, when the classification number is *5*, the value of the loss function is *0.0022*. The loss function value is little difference between classification number *4* and *5*.

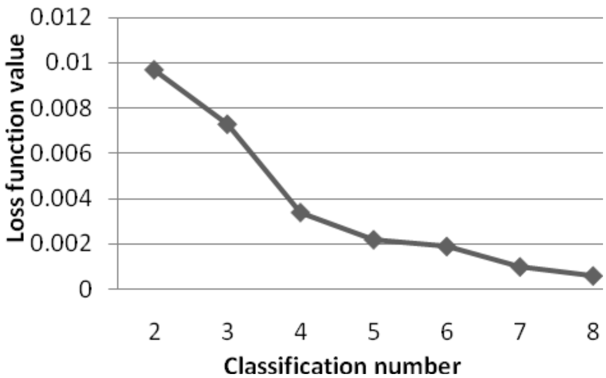

Figure 3. The value of the loss function under different classification number

Considering the convenience, take 4 as the optimal number of classification. So the optimal classification is *{1,2}, {3,4}, {5,6, ..., 12}, {13, 14,15}*. Convert the classification to the corresponding time period, the following results were obtained: *6:00-8:00, 8:00-10:00, 10:00 -18:00, 18:00-20: 00*.

Step4. The average travel time and travel costs are obtained in different characteristic period, as shown in Table 6-2:

Table 4 Travel cost / time in different characteristic period

	6:00-8:00	8:00-10:00	10:00-18:00	18:00-20:00
$\bar{t}_k$ （min）	28.333	35.625	30.5	33.5
c_k	28.333 c_0	35.625 c_0	30.5 c_0	33.5 c_0

c_0 is vehicle costs of *1* min.

When the unit operating time is *30*min or *15*min, using the same method as above to divide characterized periods, the travel time fluctuation can be further described more accurately.

4.2. Vehicle scheduling program

According to a known schedule, the following data can be calculated:

t_h (Vehicle headways in different characteristic period) and $\overline{t_h}$ (average vehicle headways in different characteristic period);

According to formula (2-1) and (2-2):

$$G_T = \frac{T_T}{\overline{t_h}}(veh);$$

$$m = \max\{m_1,\ m_2,\ldots,m_K\} = \max\{\sum_{i=1}^{I} G_{Tik}\},$$

Get the basic number of vehicles *m=21*.

In this bus line, the total vehicles number is *21*, total trips number is *270* (*136* uplink trips, *134* downlink trips).

Get the sets: $P = \{P_i \mid i = 1, 2, \ldots, 21\}$; $J = \{J_j \mid j = 1, 2, \ldots, 270\}$,

21 vehicles to be allocated are applied to the model as above. And the optimal vehicle scheduling program is obtained by using the algorithm as above.

5 Conclusions

1) Based on vehicle real-time GPS data， the transit vehicle scheduling is modeled, which takes into account the actual traffic conditions and passenger flow situation, making the capture of the technical parameters more delicately. Therefrom the vehicle scheduling plan is more informational and intelligent;

2) By the ordered clustering of travel time and Fisher algorithm the characteristic periods are divided, thereby the operating costs of each characteristic period are analysed, and it is applied to vehicle scheduling optimization model;

3) In the model of the vehicle scheduling problem, under the vehicle-trips matching, the vehicle scheduling problem is converted to the general fixed job scheduling matters. This can get the optimal vehicles-trips matching solution with the minimum vehicles quantity and the minimum total operating costs.

References

Chuan-jiao, S. and Z. Wei, et al. (2008). "Scheduling combination and headway optimization of bus rapid transit." Journal of Transportation Systems Engineering and Information Technology 8 (5): 61-67.

Haghani, A. and M. Banihashemi, et al. (2003). "A comparative analysis of bus transit vehicle scheduling models." Transportation Research Part B 37 (2003) 301–322 37: 301-322.

Kliewer, N. and T. Mellouli, et al. (2006). "A time–space network based exact optimization model for multi-depot bus scheduling." European Journal of Operational Research 175: 1616-1627.

Lin, M. and L. Wen-quan (2009). "Research on transit vehicle scheduling model and its algorithm." Journal of Transportation Systems Engineering and Information Technology 7 (003): 64--67.

Liu, Z. and J. Shen (2007). "Regional bus operation bi-level programming model integrating timetabling and vehicle scheduling." Systems Engineering-Theory \& Practice 27 (11): 135--141.

Rodrigues, M. M. and C. C. de Souza, et al. (2006). "Vehicle and crew scheduling for urban bus lines." European Journal of Operational Research 170: 844-862.

Valouxis, C. and E. Housos (2002). "Combined bus and driver scheduling." Computers & Operations Research 29 (3): 243--259.

Xinmiao, Y. and W. Wei, et al. (2001). "Peak curve of bus scheduling optimization." Journal of Southeast University (Natural Science Edition) 31 (3): 40--43.